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Chapter 8
Distributing Water Between Competing Users in the Netherlands

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Abstract The Netherlands is a delta country where water is usually abundant. Large investments in water infrastructure aim to prevent flooding, maintain shipping transport routes, irrigate farmland and ensure the health of polder lands and nature. During the limited periods when water is scarce, agriculture is low on the priority list for water allocation: farmers may be restricted in expanding irrigation operations or be even temporarily forbidden from using the equipment already installed. This comes at a cost to agricultural production. Water in this context is a unique economic input that is not privately owned, not always scarce, and not always allocated according to market principles. Nonetheless, the framework of a computable general equilibrium model (CGE) can be very effective in assessing economy-wide changes from periods of water scarcity and weighing this against policy initiatives to reduce water scarcity. In this chapter we explore adaptation possibilities to water scarcity from climate change with a particular focus on the challenges of interpretation of the CGE methodology for water in the context of the Netherlands.

This chapter reproduces with permission substantial portions of Koopman et al. (2015, 2017).

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8.1 Introduction

One of the climate change scenarios that has been developed for the Netherlands predicts hotter and drier summers and a substantial drop in river discharge in summer. This is expected to lead to increased water scarcity with potentially detrimental economic and environmental effects. The summer of 2018 was one of the driest years on record and according to a recent review by Coumou et al. (2018) this hot and dry extreme weather could occur more often as part of a persistent pattern in the mid-latitude region of the globe. Global climate change exerts significant pressure on the way that we allocate our limited water resources across different water uses and user groups. Different countries apply different allocation rules, varying from national top-down command and control policies to local or regional water markets and transboundary river basin treaties. In examining adaptation responses to climate change, such as updating water infrastructure, economic analysis can play an important role in reducing costs and improving efficiency (Hughes et al. 2010).

Traditionally questions of water distribution for economic use have been the realm of engineering models. More recently hydro-economic models which include economic principles, in the form of water demand functions, have been used to optimize the allocation of existing water resources (Harou et al. 2009). In the past two decades, Computable General Equilibrium (CGE) models have seen increasingly wider use in the economic assessment of water allocation and policy Brouwer and Hofkes (2008). The use of CGE models to examine water policy dates back at least to Berck et al. (1990) who examined the economic costs of transferring water from agricultural to recreational use in California. Later papers have added increasing levels of water heterogeneity in time (Goodman 2000), in space (Diao et al. 2005; Liu et al. 2016) as well as distinguishing between surface and groundwater (Diao et al. 2008) and desalinated water (Gomez et al. 2004).

Ponce et al. (2012) reviewed this literature, and among their findings is the general lack of detail in non-agricultural sectors and in industrial water-using sectors in particular. Further, they found that most studies essentially examine a loss of water productivity instead of an explicit loss of water availability. Some notable exceptions to this are Gomez et al. (2004) and Goodman (2000), who examine market water allocation in the Balearic Islands and the Colorado river respectively. In these studies there is a "raw water" endowment which is transformed into agricultural or municipal water before use in these sectors. Goodman (2000) also makes the distinction between water available at various times of the year and allows the market price of water to fluctuate with the demands in time of the various users.

Adaptation to climate change is defined by the IPCC (2014) as "the process of adjustment to actual or expected climate and its effects". Several types of adaptation can be distinguished. A well-known distinction is that between planned (anticipatory)

Table 8.1 The three studies examined in this chapter, the adaptation mechanisms and the model characteristics central to the study

The study and model	Adaptation mechanism	Water modelling characteristics	Assumptions on water use
1st study uses model 1 (GTAP-W)	Autonomous market adaptation	Irrigation water as explicit endowment in agriculture	Explicit water use restricted to agriculture. Additional abstraction of groundwater not allowed
2nd study, uses model 2 (distinction between surface and groundwater)	Increased investment in irrigation infrastructure	Surface and ground water as separate endowments for irrigation in agriculture	Explicit water use restricted to agriculture. Groundwater abstraction limited only by irrigation infrastructure
3rd study, uses model 3 (physical water markets)	Explicit water market across multiple sectors	Water as explicit endowment in agriculture, industry and public water services. Water market allows for trading between sectors	Explicit water use in agriculture, industry and public water services. Additional abstraction of groundwater not allowed

and autonomous (reactive) adaptation (Smit et al. 2000). In this chapter we explore market adaptation responses to water scarcity from climate change in the Netherlands by examining aspects of three studies, each of which uses a CGE model. The first (Koopman et al. 2015) explores the extent of the autonomous market response. That is autonomous adaptation by economic agents that is triggered by market/price signals. The second study (Koopman et al. 2018, in preparation), explores the planned adaptation of increased investment in irrigation water infrastructure in the agricultural sector. The third study (Koopman et al. 2017) explores the planned adaptation of introducing explicit water markets between industry, agriculture and public water services (Table 8.1).

In the first and third studies, we focus on surface water that is supplied by rivers and through precipitation. We assume that groundwater deposits are not (further) depleted i.e. that renewable groundwater is used sustainably, so the groundwater level plays no role in the analysis. In the second study we relax this assumption and assume that groundwater abstraction is limited only by irrigation infrastructure rather than physical water availability. The reality will most likely be somewhere in the middle of these two extremes as it is expected that groundwater abstraction can be on average increased slightly but not without limitation. This assumption on the availability of ground water in the second study leads to a positive impact on overall crop growth in the Netherlands from a warmer climate, while in the first and third studies the direct impact of climate change on crop growth is negative. In all three studies there is a separate public water services sector that supplies drinking water to all sectors and households. The raw water needed to supply this sector is considered in the third study, and left out of the analysis in the first and second studies.

8.2 Water Use in the Netherlands and the Impacts of Climate Change

The Netherlands is a delta region and water is deeply interwoven with the Dutch economy and way of life. Two major rivers flow into the Netherlands. The Rhine from Germany and Switzerland and the Meuse from Belgium and France. These rivers provide many economic services which range from allowing commercial and recreational shipping and groundwater recharge, to providing irrigation water and preventing the sea water from infiltrating the groundwater which would otherwise degrade the productivity of farmland. The countries that share these two rivers are linked economically and politically, and they draw much of their water from the same sources.

In the Netherlands, agriculture accounts for a relatively small 3% of total water withdrawals (Eurostat 2014; Hoogewoud et al. 2013), compared with 24% of total water withdrawals in Europe (Collins et al. 2009) and 80% globally (Rosegrant et al. 2002). However, very little abstracted water is actually consumed in other uses, roughly 10% for various manufacturing industries and less than 2% for cooling in electrical power generation (Scharf et al. 2002), whereas agriculture consumes approximately 70% of abstracted water (Collins et al. 2009).

Even though agriculture is a relatively small water user in the Netherlands; it is the focus of this chapter. The reason for this is that agriculture is considered a low priority economic sector as opposed to the other economic uses of water and in times of water scarcity other sectors will have priority for the available water. Hence any scarcity will be first felt by the agricultural sector. This prioritization is in keeping with the “verdringingsreeks”, a priority use list for water uses and users in the Netherlands (Ministerie van Verkeer en Waterstaat 2009).

Water users in the Netherlands can draw their water from both groundwater and surface water sources. Groundwater and surface water sources each have their own set of hydrological characteristics and alternative uses that are taken into account when deciding what restrictions should be placed on abstraction for irrigation. For example, the supply of surface water reacts much more immediately to changes in precipitation, while groundwater reacts more slowly and can be used as a short term buffer in times of relative drought. Moreover, the health and stability of the soil in many areas of the Netherlands is critically dependent on the level of groundwater as are many important nature areas and maintaining current levels of groundwater is therefore one of the main priorities of water managers (Ministerie van Verkeer en Waterstaat 2009).

For a low-lying country such as the Netherlands, sea and river flooding is generally considered to be the most serious threat from climate change. Yet, two of the four climate change scenarios that were drafted by the Netherlands Royal Meteorological Institute (KNMI) predicts substantially warmer and dryer summers and a significant decrease in summer discharge by 2050 of two of the Netherlands' major rivers, the Rhine and the Meuse (van den Hurk et al. 2006; te Linde 2007). The threat of water scarcity brings challenges to many aspects of Dutch society, from the supply of drinking water to production in agriculture and industry, the health of ecological systems, and the stability of water infrastructure such as levees and dikes (Klijn et al. 2012).

Climate change may have mixed impacts on global markets. For example, countries around the Mediterranean might have a serious reduction in agricultural production from higher temperatures and reduced rainfall. In contrast, warmer temperatures might create favorable agricultural conditions in Greenland and other northern areas. Similarly, rising sea levels might threaten many world ports, but warmer temperatures might also open up new trade routes in the arctic, reducing transportation costs. Therefore for simplicity, in this chapter we restrict our attention to the impact of climate change on water scarcity to the Netherlands. Without knowing the structural changes in global trade patterns from climate change we assume that the pattern of global trade, i.e. the demand for Dutch exports and the availability of imports into the Netherlands, will remain unchanged by the changing climate.

8.3 Models and Data

8.3.1 Models

The models used in the three studies are extensions of the GTAP-W model first introduced by Calzadilla et al. (2010). The GTAP-W model from Calzadilla and co-authors is itself an extension of the GTAP model (Hertel 1997).

GTAP-W extends the GTAP model by including more detail into the land endowment for agricultural producers (which are the exclusive users of the land endowment), splitting the original endowment into rain fed, irrigated, and pasture land based on the value of production of these commodities and then further splitting off irrigation water from the irrigated land endowment. All of the new land and water endowments in GTAP-W inherit the partial mobility parameter from the original land endowment in GTAP. In GTAP-W, in the lowest nest of the CES production function, crop farmers determine the level of irrigation based on the relative prices of land and irrigation water and the technical ease of varying the level of irrigation water on a given piece of land. In higher nests of the production function, the irrigated land is combined with capital, labor, and intermediate goods (seeds, fertilizers, pesticides) to produce an output like wheat or sugar beets. The CES production nest for the GTAP-W model is shown in Fig. 8.1 focusing on aspects most relevant to this paper.

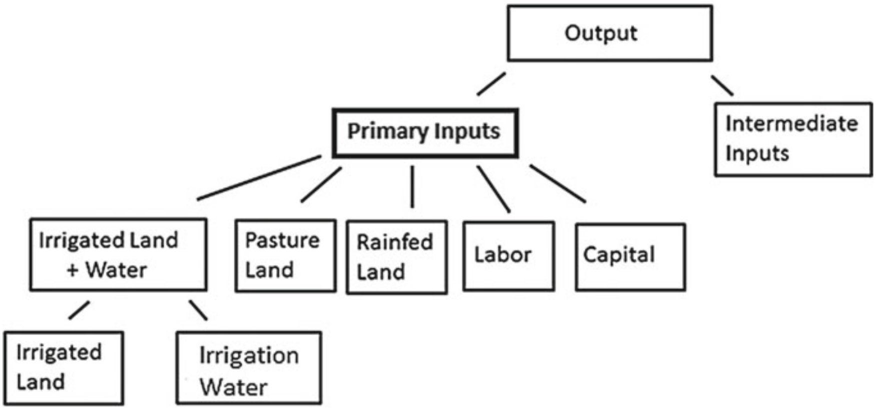

Fig. 8.1 The CES production nest for agriculture in GTAP-W (model 1). *Source* Koopman et al. (2015), Fig. 1

For the second study we use an extension of the GTAP-W model. Here the irrigation water and irrigable land endowments from GTAP-W have been replaced by four endowments: irrigation from groundwater (GW), land irrigated by groundwater, irrigation from surface water (SW), and land irrigated by surface water. Further, the structure of the CES function has been adjusted such that all land endowments related to crop agriculture are placed in a single nest "crop land" at the same level as labor, capital and pasture land. The crop land aggregate is then further split into rain fed land and the irrigated land composite. The irrigated land composite is further split into a surface water composite and a ground water composite, which are then each split into an irrigable land and irrigation water component respectively. The new production structure for model 2 is shown in Fig. 8.2.

In model 3, we use a separate extension of the GTAP-W model. We separate the value of physical water from the rest of the irrigation water endowment. The irrigation water endowment from the GTAP-W model has been replaced by an irrigation water composite which is the combination of physical water volumes and dedicated irrigation water capital. Figure 8.3 shows the decomposition of the irrigation water composite in model 3. The rest of the CES production nest for agriculture including the irrigated land endowment and the irrigated Land + water composite are the same as in model 1 (see Fig. 8.1).

In contrast to agriculture, the manufacturing and public water services sectors combine water with capital (not land). The production for these sectors is shown in Fig. 8.4. The possibility of substitution between water and capital is in line with the findings of Renzetti (1992) and Dupont and Renzetti (2001) who assert that intake water may be a substitute for recirculation water which is more capital intensive. Alternative forms of irrigation—flood, sprinkler, drip—also have different capital and water intensities. The CES for the crop sectors however has capital as an direct input in the primary inputs nest and not directly as a substitute for water. The value

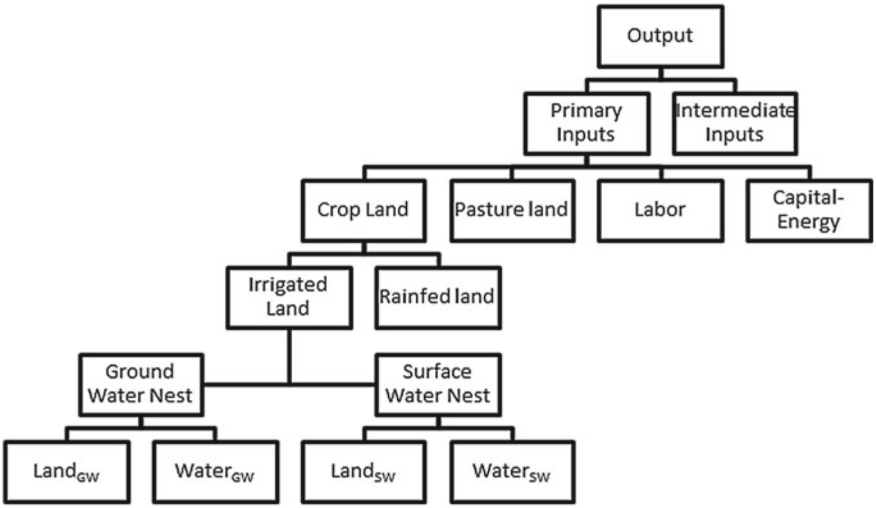

Fig. 8.2 The production structure used in model 2

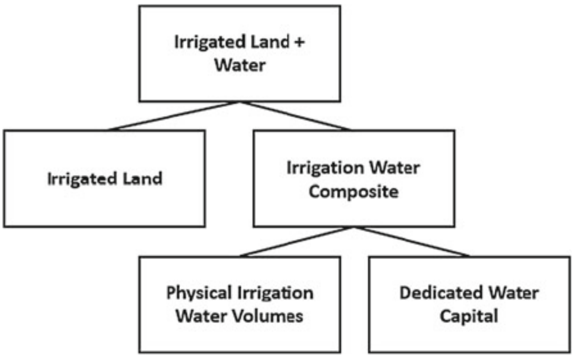

Fig. 8.3 The decomposition of the irrigation water composite in model 3

of the industry water composite is then defined as the firm expenditure on water abstraction, purification prior to use as well as discharge after use. The activities represented by the industry water composite can be substituted for expenditure on recirculation water which is assumed to be part of the capital endowment. These assumptions are in line with Goodman (2000) and Gomez et al. (2004) who combine water with capital in their models in a similar way.

We further extend model 3 by accounting for volume flows of water between sectors. This addition is necessary to insure a physical water balance when water is exchanged between very different types of use. In GTAP-W as presented in Calzadilla et al. (2010), the agricultural water endowment (renamed here the agricultural water composite) represents all of the benefits (and also the expenditure) of irrigation for production. This includes everything involved in irrigation, not only physical water but also irrigation equipment. We make the same assumption that the values of the

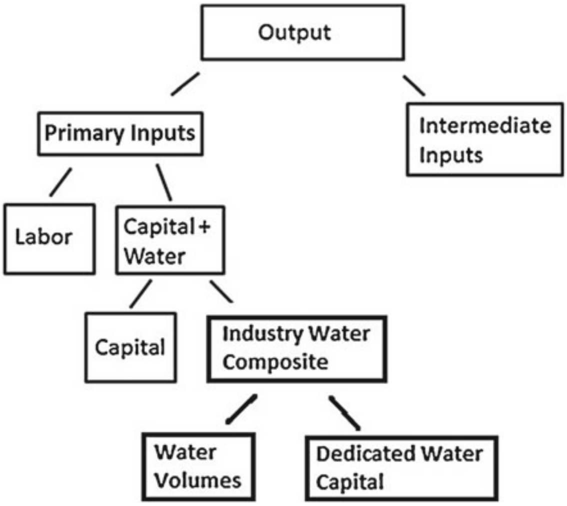

Fig. 8.4 The constant elasticity of substitution (CES) production nest for non-agricultural activities in model 3. *Source* Koopman et al. (2017), Fig. 2

agricultural and industrial water composite include not only the water itself but also the value of all of the necessary machinery for the water activity.

As the agricultural water endowment in GTAP-W is measured in millions of dollars, any redistribution of the endowment among agricultural sectors redistributes the value of irrigation without an explicit accounting of water volumes. If one assumes that the added value of a cubic meter of water is roughly the same for all agricultural sectors, then this is a reasonable structure for examining a market for water (or for water use rights) in agriculture. However, study 3 examines water redistribution where the ratio between the value of the water activity in production (the value of the agriculture or industry water composite) and the volume of water involved in that activity can vary quite substantially between uses, and this needs to be accounted for to ensure that the total volume of water before reallocation is the same as the total volume after reallocation.

To separate the value of physical water from the rest of the agricultural water endowment, we have changed the name of irrigation water 'endowment' to irrigation water 'composite', and split it up further into physical water volumes and dedicated agricultural water capital (see Fig. 8.3). Similarly, for the public water services sector and the manufacturing sectors, we first split off the industry water composite from the rest of the capital endowment where the industry water composite includes the value of all expenditures on water-related activities of abstraction, purification, use in production, and discharge. We then further split the industry water composite into the value of physical water volumes and dedicated industry water capital, which represents the value of water equipment (see Fig. 8.4). Dedicated water capital is immobile. Physical water volumes are mobile in principle, but the mobility is restricted in various policy scenarios to simulate the various water market alternatives. The physical water volume endowment is combined with dedicated water capital with Leontief production technology (no substitution allowed). The immo-

Table 8.2 Sector aggregation used in the reporting of results of the three studies

Sector aggregation
Wheat
Cereal crops
Vegetables and fruits
Sugar beets
Other crops
Public water services
Manufacturing
Services and other

bility of dedicated water capital and the Leontief production technology between dedicated water capital and physical water volumes means that the value of the water composite is completely determined by the amount of physical water available and that a percentage reduction in the amount of available water for production results in the same percentage reduction in the water composite.

In the Netherlands, there is no market for self-abstracted raw water. Determining the exact value share of the water composite that should be attributed to the water volume endowment if the firms were to be granted property rights over the water that they use was beyond the scope of the study. See Appendix 2 of Koopman et al. (2017) for details on the procedure used to estimate the relative value shares of the endowments of physical water volumes.

8.3.2 Data

All three studies use version 6 of the GTAP database (Dimaranan 2006). This database has 87 regions each with 57 sectors, which together describe the global economy in 2001. The sector aggregation examined in this chapter is shown in Table 8.2.

The methodology for splitting the value of the land endowment from the GTAP data follows Calzadilla et al. (2011a, b), where pasture land is the value of the original land endowment used by the Animals sector, the value of rain fed land is split from the value of the irrigated land–water composite by the fraction of rain fed crop production to total production. The value of irrigation water is split off of the land–water composite using the ratio of rain fed yields to irrigated yields as shown in Sect. 3.4. Irrigation water is a composite for everything involved in creating additional yields in irrigated land. The value attributed to irrigation water (the irrigation water composite in model 3) defined in this way is not simply the water itself, but everything involved in irrigation, including equipment.

8.3.3 Elasticities of Substitution

The elasticity of substitution between the irrigated land endowment and the agricultural water composite is 0.1. The elasticity of substitution between capital and the industrial water composite for the manufacturing sectors is 0.5 and 0.1 for public water services. The elasticities of substitution were calibrated such that a 10% reduction in water availability would induce the same price-water elasticities that are given in Rosegrant et al. (2002).

In model 2, we assumed that irrigated and rain fed agriculture produce the same (or very similar) crops and therefore an increase in irrigated agriculture would not necessitate a similar increase in the production of the rain fed product. This would not be the case for example if within the aggregated vegetables and fruits sector irrigated agriculture was primarily apples and rain fed agriculture was primarily carrots. Therefore, it was assumed that irrigated land and rain fed land are nearly perfect substitutes and consumers were indifferent between the two. The same assumption was made for the groundwater and surface water aggregates. Therefore the elements of the Crop land nest and in the irrigated land nest have a very high substitution elasticity of 3. The elements of the groundwater nest and the surface water nest were calibrated such that a 1% increase in the productivity of irrigation water (surface or ground) would result in a higher and not lower demand for the irrigation water endowment. This resulted in each having an elasticity of 1. The elasticities of substitution among the elements of the primary inputs nest differ per sector and were taken from the standard GTAP model. It was assumed that it is not possible to substitute between intermediate and primary inputs.

8.3.4 Ground and Surface Water

In the second study, the value of the rain fed land and the irrigated land composite, as well as the value of the surface water and ground water nests (see Fig. 8.2) are all derived from the value share of production using the same methodology as Calzadilla et al. (2011a, b).

For both the groundwater and surface water nests, irrigated land is split from irrigation water by comparing the ratio of irrigated yields to rain fed yields, where the value of the additional yields from irrigated production is attributed to water. The equation for splitting the value of irrigation water from irrigated land for each crop in each region is shown in Eqs. 1 and 2 below (modified from Calzadilla et al. 2011a). For more detail on GTAP-W see Calzadilla et al. (2011a, b).

$$Lnd_{j,r} = LndWatC_{j,r} * \left(\frac{YRF_{j,r}}{YIRG_{j,r}} \right) \tag{8.1}$$

$$Wat_{j,r} = LndWatC_{j,r} * \left(1 - \frac{YRF_{j,r}}{YIRG_{j,r}} \right) \tag{8.2}$$

where:

LndWatCj,r	The value of the Land-Water composite
Watj,r	The value of the Water endowment
Lndj,r	The value of the Irrigated Land endowment
YRFj,r	The rain fed yield
YIRj,j	The irrigated yield

for all crops j and for all regions r.

Therefore the value of land irrigated by groundwater is split from the value of groundwater irrigation by comparing the yield ratio between groundwater irrigated agriculture to rain fed agriculture, and applying Eqs. 1 and 2. The surface water aggregate is split in the same way.

For the value of the production of rain fed agriculture, and irrigated agriculture by ground water and surface water in the Netherlands we used data from the Netherlands Hydrological Instrument (NHI) (Hoogewoud et al. 2013) and the AGRICOM crop model (Mulder and Veldhuizen 2017). The AGRICOM model provided data on how yields would change in the Warm+ climate scenario described in van den Hurk et al. (2006). The NHI model includes detailed information on river flows as well as the needs of nature and other demands on water use. It therefore assumes restrictions on the surface water available for irrigation. There are no policy restrictions on ground water abstraction, and the NHI model assumes that the only restriction on the volume of abstracted ground water is the capacity of the current irrigation infrastructure. In contrast, the Deltares Delta Program Phase 3 data, which was used in the first and third study, are based on calculations that do not allow an increase of groundwater abstraction. The more conservative assumptions regarding ground water abstraction in the Delta Program Phase 3 resulted in yield losses in the warmer climates studied, while the assumed ground water availability in the NHI data used in the second study combined with an increase in irrigation water abstraction allows for an increase in yields in the warmer climate of the Warm+ scenario.

8.3.5 Splitting Water and Capital

In order to determine the value of the water composite for the manufacturing sectors in the third study, we used a survey by Scharf et al. (2002) of Canadian manufacturers, which details expenditure on water extraction, treatment, recirculation, and discharge for several manufacturing sectors. We transferred these expenditures to our model regions by using the number of employees per manufacturing sector from Scharf et al. (2002) and Eurostat (2012) as a scaling factor. The value of the industry water composite for the non-European region was determined by imposing the same ratio of the value of the water composite to the value of capital as the rest of Europe region. In the Manufacturing sectors in the Netherlands, the share of expenditure on water abstraction, treatment and discharge compared with the total expenditure of the sector ranges from the low end of 0.05 and 0.1% in other manufactures and food products respectively to a high of 0.5% in metal manufacturing. For the value of the water composite in the public water services sector, we relied on Teeples and Glyer (1987) who estimated a constant cost share of raw water of 18%.

For volumes of water used in the manufacturing and public water services sectors in the third study, we used data from the Eurostat website (Eurostat 2014). For the Dutch irrigated water volumes we used data from Hoogewoud et al. (2013). These differ substantially from the Dutch irrigation data from the Eurostat website, but we used Hoogewoud et al. because it is consistent with the Delta Program Phase 3 data which we used for the value of Dutch crop production and the direct effects of climate change on agriculture.

In estimating the water volumes used by industry, we ignore water used for cooling, which takes place mostly in the energy sector, but also in certain types of manufacturing. Water used for cooling is a process which involves abstracting large volumes of surface water, but returning virtually the same quantity and quality, only slightly warmer. As water for cooling involves very little consumptive use, it does not necessarily involve a trade-off between users. An exception is if the water temperature is already quite high, then warmed water could affect the ecosystem where it is discharged. Trade-offs between water for environmental and economic use and the resultant feedbacks of water quality on economic use are beyond the scope of this paper (see Brouwer et al. 2008; Dellink et al. 2011; Zhu and van Ierland 2012 for studies that include water quality in assessments of water for economic use).

8.3.6 The Nature of the Water Endowment

The water endowment represents the value of the sector's abstraction of raw water and equipment required for abstraction, use and discharge. The value represented by the water endowment does not include payments to the public water services sector for drinking water.

The Netherlands is a delta country where water is usually plentiful; it has relatively high or low levels of irrigation depending on how it's defined. Dutch farming is capital-intensive and there is a relatively high amount of irrigation equipment but they are only activated on unusually hot and dry days, and there is less water used in farming compared with other countries. Therefore even though there is a large proportion of farms equipped for irrigation, relatively little water is used in irrigation.

The Netherlands has a heavily developed infrastructure system for controlling and directing river water. It also has significant shallow groundwater resources. Most days irrigation water will not be restricted and there is excess supply but on certain hot dry days of the summer the demand for water will exceed the pump capacity or capacity of the canal network to deliver the water to where it is needed. There may also be an irrigation reduction or ban imposed on farmers by the water authorities to meet other water demands. Such demands include regulating water levels in the polders, ensuring sufficiently high groundwater levels for nature and preventing salt water intrusion into the fresh water systems. In these cases, water restrictions due to policy or physical infrastructure results in a water demand exceeding supply. This is leads to a reduction in potential growth for crops.

The water endowment in this study is defined as the value of the ability to abstract and use water when needed, under the current infrastructure. For agriculture the value of the endowment is reflected in the value of the additional yield (see Eqs. 1 and 2).

In the Netherlands as in most places the use of raw water is not charged volumetrically. The activities of the water managers are paid for by local taxes. Large scale abstraction is subject to a license, but there is no tariff per unit of abstraction and therefore there is no water price as such. There is a shadow price of water however, which is the value added that would be created by increasing the supply of water by one unit for a particular activity. If water is abundant then this shadow price is negligible. Still if at a particular time and place, freshwater becomes scarce (meaning that not all demand can be satisfied at present conditions), the shadow price of water will rise.

As freshwater has a shadow value in times of scarcity it is a natural resource that provides economic as well as environmental services (Briscoe 2005). Young and Haveman (1985) already noted more than 30 years ago that water has unique physical properties, complex economic characteristics, and important cultural features that distinguish it from other resources. The idea that water resources management can benefit from economic principles can also be defended (Briscoe 2005), but should always take account of other, non-economic values that may restrict the scope of these principles.

As there is no market for physical water in the Netherlands we do not have data on a water price or even quantities of water used in place and time. Therefore instead of conceiving of an explicit water endowment as the value of physical water for a specific sector, we define the water endowment loosely as the value of the water activity for the sector similar to Calzadilla et al. (2010). In the case of agriculture, the value of the water endowment is calculated as the difference in yield between rain fed and irrigated land crops. Therefore, the endowment irrigation water is a composite for everything involved in creating additional yields compared with its rain fed counterpart. The value attributed to irrigation water defined in this way is not simply the water itself but everything involved in irrigation, including equipment and labor.

By defining the value of the agricultural water endowment as the added benefit to the sector of irrigation, we acknowledge that this estimate is an upper bound on the actual sector expenditure on the water activity which may be much smaller. This is most likely the case in the Netherlands as the water is not paid for and there is a lot of public infrastructure to ensure water reaches the farm. In this case the difference between expenditure on water activity and the added value from the water activity should be attributed to the value of irrigated land endowment, instead of the irrigation water endowment. So this procedure would underestimate the value of irrigated land and overestimate the value of irrigation water endowment from the perspective of firm expenditures. If a volumetric water price were implemented, then the firm might be willing to pay if the new cost of the irrigation including the volumetric price as well as equipment etc., did not exceed the current estimation of the water endowment. However the value of irrigated land would then be expected to fall. If the total expenditure on the water activity would exceed the benefits (determined by the difference between irrigated and rain fed yields), the farm would use less water either by optimizing the use of irrigation equipment to increase water efficiency or by irrigating less.

In contrast to the value of the water endowment for agriculture, the value of the water endowment for industry and public water services is split from the value of capital and defined by the expenditure on abstraction, purification prior to use and discharge. By defining the value of the water endowment in this way for the industrial sectors and public water services, this estimate is then a lower bound on the value of the water activity for the sector involved. That is, if a volumetric water price were implemented then the water using sectors might well be prepared to pay.

8.4 Selected Adaptation Scenarios

8.4.1 Water Scarcity Scenarios from Crop Models

The three studies examined in this chapter involve variations of the future dry climate based on the Warm+ climate scenario (van den Hurk et al. 2006). The first study approximates the direct impact on crop yields from the Warm+ climate scenario by implementing the direct crop yield response to the extremely dry climate of 1976 based on the Deltares Delta Program Phase 3 results, which assumes a maximum level of groundwater withdrawals and predicts a reduction in crop yields and land fertility in the Netherlands as a response to the dry climate. The second study approximates the impact on crop yields from the Warm+ climate scenario directly, using the NHI data (Hoogewoud et al. 2013) which assumes no restrictions on groundwater extraction resulting in a positive yield response to the increase of temperature under the Warm+ climate. This yield increase rests entirely on crops having enough water to take advantage of the warmer temperatures. In the Warm+ climate scenarios with particularly dry years using the NHI and AGRICOM models, crop yields will decrease since there is not enough irrigation water under current infrastructure to satisfy the needs of the plants. The third study implements the Warm+ climate scenario directly but uses the same groundwater assumptions and crop response model as the first study (Delta Program Phase 3), resulting again in a yield decrease for all crops.

Table 8.3 Climate impacts on the rain fed and irrigated land productivity in studies 1 and 3, shown in percent change

	Wheat		Cereal crops		Vegetables and fruits		Sugar beets		other crops	
Study	1	3	1	3	1	3	1	3	1	3
Irrigated land	Na	Na	Na	Na	−15	−4	−14	−12	−3	−10
Rain fed land	−13	−10	−13	−10	−37	−23	−27	−20	−27	−20

Na Not applicable
Source Based on Koopman et al. (2015, 2017), Tables 3 and 4 respectively

8.4.2 Changes to Endowments to Reflect Productivity Changes

The data sources used in the studies provide the impacts on crop production from the Warm+ climate. In the first and third studies these changes in irrigated crop production were translated to an impact on the agricultural water and land endowments using a method described in Koopman et al. (2015), by fixing prices for all elements of the CES crop production function with the exception of water and land to estimate the required change to irrigated land productivity which would result in the estimated reduction in crop production from the Delta Program Phase 3 data given a change in the quantity of the water endowment. The percent change production of the rain fed crop was directly implemented as the percent change in the productivity of rain fed land.

In the dry climate crops need more physical water to achieve the same yield. In the first and third studies the direct crop response to the dry climate was reduced crop yields and so we reduced the quantity of the water endowment by the percent difference between the volume of water required to achieve the pre-drought yields and the actual volume of water abstracted. In that dry climate the abstracted water was actually higher than the abstracted water in the pre-drought climate, however the water required to achieve the same yields was significantly higher still and therefore the quantity of the water endowment was reduced. This reduction of the water endowment was not enough on its own to reduce the crop output to the target levels in the calibration of the CES and so the productivity of irrigated land was reduced as well to achieve the remaining reduction of crop growth. Table 8.3 shows the changes to the irrigated and rain fed land productivity as a result of the warmer climate scenarios for the studies 1 and 3. The quantity of the irrigation water endowment was reduced by 22 and 11% in studies 1 and 3 respectively.

In the second study we chose a slightly different approach. Recognizing that the growth of the plants in the water scarce environment is dependent on water, we attributed all change in crop growth to the water endowment leaving the productivity of irrigated land unaffected. We then attributed the quantity of the irrigation water endowment to irrigation capital (canals, dams, water pumps and on farm irrigation systems) while the changes in climate and water availability were attributed

Table 8.4 Climate impact on the endowment productivity in the second study

	Climate impact for 2nd study, % change in productivity				
	Wheat	Cereal crops	Vegetables and fruits	Sugar beets	Other crops
Surface Water endowment	Na	Na	49	79	50
Ground water endowment	Na	Na	45	77	54
Rain fed land endowment	6.8	6.8	−4.7	−0.5	−4.3

Na Not applicable

to changes in the productivity of the water endowment and not the quantity of the water endowment. Table 8.4 shows the changes to the productivity of the surface and groundwater endowments and rain fed land as a result of the Warm+ scenario using the data from the NHI and AGRICOM models. The large changes in productivity of the irrigation water endowments reflect the fact that they represent a small portion of the total share of the surface (or ground) water nest (see Fig. 8.2), therefore even a small change in the irrigated crop production requires a large change in the productivity of the water endowment according to the calibration procedure as discussed in Koopman et al. (2015).

Here again the productivity of the water endowment is not necessarily the productivity of the physical water. In fact plants would need more water in the hot and dry Warm+ climate then they do in the current climate to produce the same yields. The productivity of the water endowment in the second study is defined as the productivity of the existing irrigation systems on the farm and the infrastructure (canals, dams) which brings water to the farm. Under the normal climate conditions a farmer might only turn on the irrigation system during the few dry periods and the rest of the time it is not used. Under the Warm+ climate conditions the same irrigation system will be used much more often, bringing more water to the plants, not only on a given day but also on more days total. This results in higher yields for the plants which we ascribe purely to the water endowment. In this way it is the productivity of the irrigation activity which is generating higher yields rather the productivity of physical water.

8.4.3 Selected Adaptation Responses to Water Scarcity

In the first study we compare the direct damage to agricultural production from the warm climate provided by the crop model of the Delta Program Phase 3 without economic feedbacks to the total economic impact of the same climate shock as calculated in model 1 which does allow for economic feedbacks. In this way the aim of study 1 is to assess the extent of autonomous adaptation to the climate shock in agriculture.

In the second study we use model 2 to compare the economic impact of the Warm+ climate scenario with autonomous adaptation to a scenario with additional investment in surface water irrigation infrastructure as planned adaptation. In this way the aim of study 2 is to assess the additional economic impact of irrigation investments as planned adaptation as opposed to only autonomous adaptation.

In the second study the crop response to the Warm+ climate scenario from the NHI and AGRICOM models suggest that if the crops which were irrigated by surface water were to receive the optimal amount of water for growth then the output would increase by over 14% compared to the Warm+ scenario crop yields under current irrigation infrastructure. In an additional scenario in the second study, using model 2 (see Fig. 8.2), we explore this possibility by increasing the quantity of the surface water endowment by 65%. In this case, the output of agriculture irrigated by surface water would increase 10% absent economic feedbacks and adjustments of other inputs by farmers. The surface water endowment was calibrated to achieve the 10% increase in production using the same assumptions on the CES production function used in studies 1 and 3 and described in Koopman et al. (2015).

In the third study, the reduction in the quantity of the water endowment as a result of the Warm+ climate was applied to the physical water volumes endowment (see Figs. 8.3 and 8.4) instead of the aggregated water composite as in studies 1 and 2. By distinguishing between water volumes and dedicated water capital in the third study we were able to ensure that in a water market between the two users that it would be physical water that would be traded and not value of water equipment. As we were unable to obtain data on the quantity changes in demand and supply of water for the manufacturing and public water services sectors we choose to reduce the water endowment of industrial water users by the same amount as the agricultural water users.

The Warm+ climate scenario predicts increased water availability in the winter. We assume, however, that extra winter water cannot be used in the summer in excess of what is already being stored under the current infrastructure. The results from the Delta Program Phase 3 suggest an 11% loss in effectively available irrigation water in the summer (we assume that all irrigation occurs in the summer). In study 3 we assume that the Warm+ scenario causes a proportional loss of water available for manufacturing and public water services, implying that there will be an 11% loss to the entire summer water supply available for economic use. We assume that the public water services, and manufacturing sectors have a constant requirement for water use throughout the year, and so, the 3-month summer water requirements of these sectors is 25% of their yearly water requirement, and the value of the summer water endowment is 25% of the value of the water endowment in 2001. To ensure that only summer production is affected by the summer water reductions, we divided all water-using sectors into a summer fraction and a rest of the year fraction (with the exception of the irrigated agricultural activities whose loss of yearly output was calibrated to a loss of summer irrigation water from Delta Program Phase 3 results.

Only the summer fraction of manufacturing and public water services is affected by water scarcity.

In the third study we compare 4 scenarios of water market allocation in the warm climate. All scenarios are implemented in model 3 and so include autonomous adaptation. The aim of study 3 is to assess the importance of water markets (or the allocation of water according to its shadow price) as planned adaption to climate change.

In these studies, the term water markets is defined rather loosely as a mechanism which allocates water for economic use according to its shadow price and accordingly equalizes the marginal shadow costs of water use across economic activities. We do not describe the institutional setup of such markets, nor the physical infrastructure and associated investment costs that may need to be in place for water markets to function properly, nor do we take transaction costs into account. In addition, water markets in our analysis should be considered more as a yearly market for water use rights (for example, in the form of an auction) rather than as a spot market to satisfy immediate short-term water use needs. Without water markets, shadow prices will, as a rule, differ across different economic activities and different locations.

1. *No water market*

In the no-water-market scenario, there is no possibility for exchanging water through a water market between sectors. That is, the water volume endowment is made immobile. This scenario is even more restrictive than the scenario calculated by models 1 and 2, as in those scenarios the water endowment was imperfectly mobile between crops so there was some reallocation of water between the crop sectors (with the same mobility as land).

2. *Two markets*

In the two-market scenario, two distinct water markets are specified. In this case, the agricultural water market supplies the agricultural sectors and the industry water market supplies the manufacturing and public water services sectors, but without possibilities of exchanging water between industry and agriculture. The water volume endowment is mobile, but a distinction is made between the water volume endowment that serves the industry water market and the water volume endowment that serves the agriculture water market.

3. *Single market*

In the single-market scenario, there is one water market that supplies all sectors. This is the most flexible option, where water can also be exchanged between sectors through the creation of a single market. The water volume endowment is mobile, and no distinction is made between the water volume endowments that serve the industrial or agricultural sectors.

4. *Single water market without public water services*

Perhaps for political or equity reasons, policy makers might find additional price increases for public water services unacceptable.Therefore, in this policy scenario,

Table 8.5 The scenarios and models examined in this chapter

Study and model used	Scenario name	Description
Study 1, (no economic model used)	Climate 1976, no adaptation	Climate impact on crop growth, no autonomous adaptation
1	Climate 1976, autonomous adaptation	Economic impact with autonomous adaptation of Warm+ agricultural conditions approximated by 1976 climate
2	Warm+ climate	Economic impact of Warm+ agricultural conditions
2	SW adaptation	Economic impact of Warm+ agricultural conditions with increased investment in surface water irrigation infrastructure as planned adaptation
3	No-water market	Economic impact of Warm+ climate conditions. Water is immobile
3	Two markets	Economic impact of Warm+ climate conditions. Water is perfectly mobile within (but not between) agriculture and manufacturing + public water services
3	Single market	Economic impact of Warm+ climate conditions. Water is perfectly mobile for all sectors
3	Single market without public water services	Economic impact of Warm+ climate conditions. Water is perfectly mobile for all sectors. Public water services is excluded

there is a single market for water-using sectors; however, the public water services sector does not participate. The public water services sector receives an 11% loss of summer water availability while the remaining summer water-using sectors collectively receive an 11% loss of summer water and reallocate the remaining water among themselves within a single market. By removing it from the water market, public water services in essence receive a subsidy such that the shadow price of water that it faces is lower than the market price of water. Table 8.5 gives a summary of the scenarios and models examined in this chapter.

Table 8.6 Percent change in the price and quantity of the agricultural activities from the first study

Scenario		Wheat	Cereal crops	Vegetables and fruits	Sugar beets	Other crops
Climate 1976, no adaptation	Price change	0	0	0	0	0
	Quantity change	−13.0	−13.0	−9.0	−26.0	−7.0
Climate 1976, autonomous adaptation	Price change	3.2	4.6	3.7	5.4	2.4
	Quantity change	−14.1	−6.8	−8.7	−3.5	−10.4

Source Includes data from Koopman et al. (2015), Table 4

8.5 Results

8.5.1 Study 1

Table 8.6 shows the results at the aggregated crop level in the Netherlands from the first study implemented in model 1. The yield shock from the warm dry climate leads to a reduced output of agricultural goods. In the "Climate 1976, no adaptation" scenario there are no economic feedbacks and so the crop prices are assumed to be constant. Further there is no reallocation of economic inputs labor, capital, land and water so the economic losses are the direct result of the reduction in crop yields.

In contrast, applying the equivalent shocks from the dry climate of 1976 to model 1 results in economic feedbacks as a response to the reduction of crop yields. Due to the price-inelastic demand for agricultural commodities, prices rise which will in turn induce some new supply from Dutch farmers. Imports into the Netherlands will also increase as a result of increased crop prices. Further farmers will optimize their production plans in accordance with the new physical and market conditions. In the first place, recognizing the physical water scarcity, they will economize on the use of water and substitute (irrigation) water for other factors of production to the extent possible. They will also change their cropping plans in accordance with the new scarcity induced market conditions.

The prices of some crops are less affected than those of others. The extent of the price increase of Dutch agricultural products in response to the higher costs of production depends on the ability of foreign imports to make up for lost domestic supply. For example, the price of sugar beets increases in particular (see Table 8.6). Due to its "sheltered" position on the domestic market (very little imports and exports) it will be more difficult for consumers of Dutch sugar beets to find new suppliers to replace them. This raises the price for sugar beets and so at the margin farmers will prioritize the production of sugar beets.

Despite the adaptation responses to the new market and water scarcity conditions, the rewards of factors of production (labor, capital) in agriculture will decrease. As a third adaptation response, some factors of production may, at the margin, seek employment in non-agricultural occupations. In equilibrium, this would lead to a general decline of wages and rentals in the economy. This leads to a decrease of income of the owners of labor and capital: the households (i.e., the consumers).

The other sectors of the economy, broadly mining, manufacturing and services, are faced with two opposing effects: first, a decrease of domestic demand because of the fall in real income of the consumers, and second, a fall in wages and capital rentals that decreases their costs of production. A profitable adaptation response would therefore be to resource the supply of their goods from the domestic market to foreign markets. This adaptation response is easier for those sectors that already sell a large share of their output abroad (manufacturing) than for those sectors that primarily service the domestic market (a large share of services). In total when only examining the yield losses at constant prices with no adaptation possibilities for farmers, the 1976 approximation of the Warm+ climate would result in a 1115 million U.S. dollar loss in value to Dutch agriculture in the no adaptation scenario. When accounting for rising crop prices as well as the reallocation of water, land and other inputs the total value losses to Dutch agriculture is 612 million U.S. dollars. Taken together the rest of the Dutch economy now also has a loss of 405 million U.S. dollars, as the cheaper labor and capital are not enough to make up for the drop in domestic demand.

From these results it can be surmised that economic autonomous adaption has several aspects that should be considered when assessing the impacts of climate change. A reduction in the supply of agricultural goods leads to an increase in price. This price increase leads relatively more production of Dutch agricultural goods than the situation without the price increase and also leads to more imports. Both responses to the price increase help to satisfy consumer demands for food. A reallocation of production factors among the crop sectors based on the relative price increases of the crops leads to a very different estimation of damage and loss from climate change than would occur if one were only to look at the yield losses from the crop models. Finally the non-agricultural aspects of the economy are affected as well. The movement of labor and capital from agriculture to the rest of the economy depresses wages and capital rentals everywhere. While this price reduction helps the non-agricultural sectors, the reduction of consumer income and increased agricultural prices negatively affect the non-agricultural sectors. Therefore in assessing the economic effects of climate change it useful to look more broadly than agriculture alone even if agriculture were to be the only sector directly impacted.

8.5.2 Study 2

The Warm+ climate scenario as calculated by the NHI and AGRICOM models results in a decrease of rain fed yields for most crops in the Netherlands (with the exception of wheat and cereal crops). The optimistic assumptions on available water withdrawals in the NHI result in an increase in the production of irrigated crops in the

Table 8.7 Percent change in price and quantity of agricultural activities in study 2

	Warm+ climate		SW adaptation	
	Quantity	Price	Quantity	Price
Wheat	4.03	−0.83	4.69	−0.96
Cereal crops	1.72	−1.10	1.99	−1.28
Vegetables and fruits	0.72	−0.29	1.60	−0.63
Sugar beets	0.01	−0.31	0.01	−0.45
Other crops	1.86	−0.39	3.31	−0.69

Netherlands in contrast to the crop model and data for studies 1 and 3. The shocks to the productivity of water and land in study 2 are shown in Table 8.4 and the results on the production of crops in the Netherlands as calculated by model 2 are shown in Table 8.7.

In the Warm+ climate scenario, which includes autonomous adaptation, even though the impact on total crop yields in study 2 is opposite of study 1 (i.e. higher yields instead of lower yields), the economic adaptation mechanisms are the same. The increase in the supply of Dutch agricultural goods naturally leads to a drop in price also shown in Table 8.7. This drop in price benefits consumers and all other economic sectors that rely on agricultural products for their inputs. Wheat increases the most and has a lower drop in price as compared to cereal crops even through both activities have the same increase in land productivity as shown in Table 8.4. Wheat is very homogeneous product with a correspondingly high Armington elasticity (Armington 1969) which allows the sector to increase its exports and sell the additional supply. Sugar beets is mostly rain-fed so even though it has a high increase in irrigation water productivity, the small productivity loss from rain fed land keeps the total increase of output very small. Even with the very small increase in output, the sugar beet sector has a relatively large reduction in price, this is because almost all of the sugar beets grown in the Netherlands are consumed by domestic markets which makes finding new avenues for exports relatively difficult. In Vegetables and Fruits and Other Crops by comparison a large proportion of domestic production is already exported (70 and 80% respectively) which makes it easier to increase exports rather than saturating the Dutch market, therefore there is relatively little decrease in the price of these products. The cereal crops sector has a large reduction in price in comparison to its increase in production (although not as large as sugar beets), indicating a difficulty increasing exports. This is a result of a relatively low share of exports compared with domestic production (35%) and a very low Armington, the lowest of all of the crop sectors.

The decline in the price of agricultural products also has an effect on the endowments. This is shown in Table 8.8. The marginal value product of surface water and land irrigation decrease slightly, while the marginal value product of the direct substitute ground water and land irrigation slightly increases. The marginal value product of rain fed land decreases substantially. Most of the rain fed land endowment is used

Table 8.8 Percent change in price for agricultural endowments in study 2

	Warm+ climate	SW-adaptation
Surface water	−0.88	−39.49
Ground water	0.59	−4.65
SW-land	−0.83	−0.60
GW-land	0.61	−4.63
Rain fed land	−9.00	−12.75
Labor	0.03	0.05
Capital	0.02	0.04

by Vegetables and Fruits and by Other Crops so even though the productivity of rain fed land increases for Wheat and Cereal Crops the average total productivity of rain fed land in the Netherlands decreases. We have assumed that similar products are grown in the rain fed and irrigated components of a single aggregated crop sector in so doing we assume that if rain fed land becomes less productive then the same crop can be grown on irrigated land without too much difficulty this is reflected in the very high elasticity of substitution between rain fed and irrigated land.

Almost all of irrigated agriculture in the Netherlands is Vegetables and Fruits and Other Crops. From Table 8.7 we see that the production of Other Crops has a larger increase as compared with Vegetables and Fruits. This in turn results in a higher demand for production factors for Other Crops as compared with Vegetables and Fruits. The surface water and land endowments are evenly distributed between the two crops however the groundwater and land endowments are primarily (about 80%) used by Other Crops. As a result the price for the groundwater and land endowments have a small price increase compared with the surface water endowments.

In the Warm+ climate scenario the price of labor and capital also increase. Demand for these endowments increases when the agricultural production increases but unlike the irrigated land endowments there is no productivity increase in capital and labor. Therefore capital and labor are the relatively scarce resources compared to the base data without the climate shock. The stock of capital and labor are very large however so the increase in wages and capital rentals is small.

Compared with the Warm+ Climate scenario, the investment in surface water infrastructure further increases the production of all agricultural activities. The production of Vegetables and Fruits and of Other Crops increase directly through an increase in the surface water endowment and it induces these two large agricultural activities to use less rain fed land which further reduces the price of rain fed land, shown in Table 8.8. Table 8.8 also shows that the reduction in the shadow price of the surface water endowment (due to the increase in supply) reduces the shadow price of ground water and land as well as this is the substitute production method of surface water irrigated agriculture. The price of labor and capital increase even further than in the Warm+ Climate scenario however this increase is not enough to offset the decrease in rain fed land rents and so Wheat and Cereal Crops can increase their output even further as their input endowments are on the whole less expensive.

The gains of the productivity increase went to the owners of labor and capital, these make up about 50% of the expenditure of Dutch farms. As we assume that labor and capital are mobile through the economy this wage increase benefits workers and investors in all sectors not only agriculture.

Rain fed farmers (or more specifically the owners of rain fed land) are on average worse off as the productivity of their farms decrease while the productivity of their competitors increases. At the margin, given soil conditions and the costs of transition, rain fed farmers might choose to grow wheat as the productivity of this crop is higher in the Warm+ climate. Wheat can be more easily exported and the alternative rain fed components of irrigated crops have a relatively difficult time competing in the Warm+ climate.

8.5.3 Study 3

Table 8.9 shows the percentage change in quantity of water use in the various water using sectors in the Netherlands in study 3 for all four different water market alternatives as calculated by model 3. The results all take place in the context of the Warm+ climate change scenario from the Delta Program Phase 3, which has more conservative estimates on water availability for irrigation than in study 2, resulting in a reduction in agricultural yields compared to the base year. In the no-water-market scenario, the supply of water falls by an equal percentage in all water-using sectors. In response to the drop in water supply, the shadow price of water rises by far the highest in the manufacturing sectors followed by the agricultural sectors and less in the public water services. This is shown in Table 8.10 which displays the percent change in the (shadow) price of water for each scenario relative to the percent change in the price of water in the single-market scenario. The underlying reason for the difference in the change in shadow price of water in response to the same percentage reduction in water is that the average value product of a cubic meter of water used in public water services is lower than in agriculture and much lower compared with manufacturing. This coupled with the Leontief production technology between water volumes and dedicated water capital leads to the marginal value product of water being much higher in manufacturing than in agriculture or public water services.

The larger economy-wide changes for the Netherlands resulting from the climate shock and the four water market configurations are shown in Table 8.11. In the no-water market scenario, GDP output has the largest loss of all the various water market configurations. Agriculture loses 2.19% of its output, by far the largest of all the water use categories. Public water services lose 0.54% of its output, comparatively little, while manufacturing actually gains overall from the water-scarce climate. This is not surprising as agriculture endures a loss of land productivity in addition to the loss of available water. Further, the various land and water endowments in agriculture account for approximately 16% of the total value of primary inputs in production for the irrigated activities and 60% of the rain fed activities (wheat and cereal crops). In contrast, the percentage of the industrial water composite in the value of primary inputs in the manufacturing sectors ranges between 4% (paper and pulp) and 0.3% (other manufacturing).

The large drop in the output of agriculture reduces demand for labor and capital services which in turn reduces their market prices (wages). The reduced price of labor and capital services more than makes up for the loss of water for manufacturing as a whole. Therefore, manufacturing faces more favorable economic conditions in the water-scarce climate.

In the two-market scenario, the water supply is reduced by the same amount as in the no water market; however, two market mechanisms now exist, respectively, between the agricultural sectors and the industrial water users. As a result, the price of physical water is equalized separately within the agricultural and the industrial water-using sectors. From Table 8.9, we see that water moves from the public water

Table 8.9 Percentage change in quantity of water use in study 3

	No water market	Two markets	Single market	Single market without public water services
Vegetables and fruits	−11	−10	−7	−11
Sugar beets	−11	−7	−5	−8
Other crops	−11	−12	−9	−13
Manufacturing[a]	−11	0	−1	−1
Public water services[a]	−11	−12	−15	−11

[a]We only consider the use of summer water
Source Modified from Koopman et al. (2017), Table 5

Table 8.10 The ratio of the percentage change in the price of water over the percentage change in price of water in the single-market scenario

	No water market	Two markets	Single market	Single market without public water services
Vegetables and fruits	2.2	2.0	1.0	2.4
Sugar beets	3.1	2.0	1.0	2.4
Other crops	1.8	2.0	1.0	2.4
Manufacturing[a]	16.5	0.8	1.0	2.4
Public water services[a]	0.8	0.8	1.0	0.8

[a]We only consider the use of summer water
Source Modified from Koopman et al. (2017), Table 6

Table 8.11 Economy-wide results for the Netherlands under the Warm+ climate change water scarcity scenario

		No-water market	Two markets	Single market	Single market without public water services
Percent change in yearly output	GDP	−0.024	−0.021	−0.021	−0.021
	Agriculture	−2.20	−2.25	−2.07	−2.33
	Manufacturing	0.04	0.06	0.05	0.07
	Public water services	−0.54	−0.59	−0.72	−0.54
Percent change in price	Capital	−0.17	−0.15	−0.15	−0.16
	Labor	−0.16	−0.15	−0.14	−0.15

Source Koopman et al. (2017), Table 7

services sector to the manufacturing sectors which have essentially no loss of water with respect to the benchmark equilibrium. Within the agricultural market, water moves from the Other Crops to the Vegetables and Fruits and Sugar Beet sectors. The reallocation of water in the two-market scenario follows the difference in water shadow price from the no-water-market scenario shown in Table 8.10. Table 8.10 also shows that the percent change in water price is substantially higher in the agricultural market than in the industry water market which gives further insight into how water will move in the single-market scenario. The aggregated economy-wide results from Table 8.11 show that in the two-market scenario, the GDP output improves compared with the no-water-market scenario, and access to more water allows the manufacturing sectors to further increase their output. More productive allocation of water also increases the demand for labor and capital which increases their price compared with the no-water-market scenario. This results in higher costs for agricultural inputs which further depress output. Sharing a water market with manufacturing causes public water services to pay a slightly higher price for its water in addition to a higher price for labor and capital than in the no-water market scenario which also causes a reduction in output.

In the single-market scenario, all water-using sectors participate in a unified market resulting in a single price for water across all uses. In this scenario, water moves from public water services into agriculture as well as into manufacturing. The agricultural sectors use more water than in the two-market scenario while manufacturing sectors use slightly less, as the water demand from agriculture drives up the price that the manufacturing sectors face for water volumes. Public water services use even less water than in the two-market scenario. The single-market scenario is the best outcome for agriculture, as agriculture has the highest output in the single-market scenario compared with all other scenarios. Manufacturing does slightly worse than in the two-market scenario, and public water services have the largest loss in the single-market scenario compared with all other scenarios, as it faces higher prices for water, labor, and capital than in the other market scenarios.

Finally, we examine the scenario where there is a single market for water, but public water services do not participate and so only suffer the direct loss of 11% of its raw water supply. From Table 8.6, we see that as the water from public water services is not available, water moves from the agricultural activities to the manufacturing sectors. On the whole, agriculture has less water available to it than in the no-water-market scenario, but the remaining water is more productively allocated across the agricultural activities. The more efficient allocation of water within agriculture is not enough to offset the additional loss of water. In terms of total output, this is the worst scenario for agriculture. Manufacturing gains the most from this scenario, as the depressed price of labor and capital more than compensate for the higher price for water compared with the single-market and two-market scenarios.

Table 8.11 shows that even though instituting a water market increases overall output, any particular instance of the three water market possibilities considered will have winners and losers from the perspective of sector output. The particular winners and losers can be seen by examining the shadow price of water for each sector in the no-water market scenario (Table 8.10). If a sector's water shadow price is lower than the shadow prices of the other possible participants in a market or lower than the eventual market price of water in any instance of market, then the sector will loose from creation of a market. On the other hand, any sector with a higher shadow price for water than the eventual market price will gain. Put another way, a sector with a water shadow price in the no-market scenario that is lower (higher) than the market price for water that would exist in the instance of a particular water market is essentially receiving a subsidy (tax). Creating that water market would remove the subsidy or tax.

Further it is worth noting, that even though the single water market scenario is preferable from the standpoint of economic efficiency there may be other objectives in designing a planned adaption response to climate change, for example maintaining similar sector output levels in the new water scarce climate as in the base year. Agriculture has the largest losses from the water scarce environment while the manufacturing sector actually increases production in all water market scenarios including the no market scenario. There are two main reasons for increase in manufacturing, the first is that the industry water composite is combined with capital (Fig. 8.3) with a relatively high elasticity of substitution (0.5 compared with 0.1 for agriculture). The value of the capital expenditure is also very large compared the value of the water composite making substitution of the water composite with other inputs comparatively easy compared with the other sectors. Further the manufacturing sectors can take advantage of the reduced prices for labor and capital which result from the reduction in demand from the agricultural sectors. However, even though the output of the manufacturing sectors is less dependent on water availability than the other sectors it does have the highest shadow value of water compared with agriculture and public water services i.e. the manufacturing sectors have the highest ratio of expenditure on the water composite per unit of water compared with the other sectors.

Therefore if manufacturing enters into a water market with any of the other sectors, water on average will be allocated to the manufacturing sectors from the other sectors in the market.

The two markets scenario is also negative for agricultural output compared with the no market scenario even though agriculture does not participate in a market with manufacturing and water is more efficiently allocated within agriculture. The increased output of manufacturing in the two water markets scenario increases the demands on labor and capital which raises their prices compared with the no water market scenario. This analysis points again to the notion that it is important to look beyond the elements and actors directly participating in an adaptation intervention when assessing its impact.

8.6 Discussion and Conclusion

This chapter explores a range of interpretations and applications of the water endowment in a computable general equilibrium model to assess adaptation mechanisms to water scarcity from climate change. Three similar studies of economic adaptation in the Netherlands were examined. The first study examined autonomous adaptation as response to climate induced water scarcity while the second and third studies examined respectively investments in irrigation infrastructure and the introduction of a market for water as planed adaptation. All three studies found that when assessing the economic impacts of climate change it is important to look at the larger economy wide effects including the sectors that are not directly affected by the aspect of climate change under examination. In the first study for example the rising prices for agricultural products already partially compensated agricultural producers for their loss of output although the price increases were not uniform per crop type. The non-agricultural sectors on the other hand were not directly affected by the hot dry climate in this analysis but they were negatively affected by the reduction in Dutch consumer income and the increased price of agricultural inputs. This insight is useful in deciding where and how much to target policies aiming to reduce negative climate impacts on particular sectors or how they might be compensated for losses due to climate change.

The same is true when estimating the effects of a planned adaptation policy as examined in studies 2 and 3. It is important to look beyond the effects on the sectors directly affected by the intervention. In the second study the increased investment in surface water irrigation infrastructure helped farmers with access to surface water to take full advantage of the warm climate to increase their output. However the reduced crop prices which accompanied the increase in total crop output also affected the rain fed farmers as well as irrigated farmers with only access to ground water. In the third study the implementation of water markets increased the economic efficiency of the allocation of water, the scarce resource, and increased overall economic output. However, any sector participating in a water market with the manufacturing sectors would further reduce their output. Even in the two market scenario when agriculture was not participating in a water market with the manufacturing sectors, the increased economically efficient allocation of water allowed manufacturing to further increase production and in so doing increase the demand for and price of other resources (labor and capital) that are also needed in agriculture. These economy wide affects make an strong argument for the use of CGE models in assessing the impacts of water scarcity from climate change.

By examining these studies together we also make a methodological point that even in a single country such as the Netherlands interpretations of the water endowment can vary significantly. This is particularly true when the water endowment represents both the value of the water itself and also all expertise, capital etc. required to utilize the water resulting in increased consumption of the crop and higher crop yields.

The water endowment can be widely interpreted to mean many things and changes in the quantity, value and productivity of the endowment can in turn be interpreted in many different ways. To make a link with physical water it is important to be explicit about what the water endowment represents and if there are shocks to the endowment, where these shocks come from. As the studies 1 and 2 show the quantity of the agricultural endowment could equally be interpreted as the quantity of water or the quantity of machines and expertise on the farm to utilize that water. In the later a change in the availability of physical water results in a change in the productivity of the water endowment rather than a change in the quantity.

By separating out physical water from dedicated water capital in the second study, there is more clarity in the interpretation of a change in physical water availability. However this approach required some strong assumptions about the dedicated water capital endowment, namely that it was sector specific, with no elasticity of substitution between water volumes and dedicated water capital. This last assumption was necessary as self-abstracted physical water volumes don't have a volumetric price or value in the Netherlands, so the value of water had to be tied explicitly to the value of another endowment In any case being explicit about the interpretation of the water endowment in the scenarios examined can bring clarity in the interpretation of the value of water in various economic uses during times of scarcity.

Looking at the reactions of various economic sectors to the same water scarcity conditions, we can see that the impact on the sector from water scarcity is not merely determined by the nature of the water endowment itself but many other parameters in the model as well. Whether climate change and irrigation water availability positively (studies 1 and 3) or negatively (study 2) affect crop yields in the Netherlands, it is the mobility of endowment factors capital, labor and water which often determine the mitigating effects internal to the country. If a sector has a deficit (or abundance) of the water/land endowment, the mobility determined the ease with which it can attract other inputs. All three studies assume perfect mobility of labor and capital across all sectors. This assumption is important in determining, both the extent of the autonomous adaptation response to climate change and also the extent to which various economic actors suffer (or benefit) from the adaptation responses. In studies 1 and 3 a contracting agricultural sector has less demand for labor and capital which reduces their price. The assumption of perfect mobility allows these endowments to be used as inputs for the other economic sectors which mitigates the drop in price for agricultural labor (for example) which although is beneficial for agricultural laborers does mean that the farm owners must pay more for labor than would be the case in more segmented factor markets. In study 2, the increase in land and water productivity means that capital and labor are the relatively scarce resources in the production of the crops. In a more segmented factor market then the prices of agricultural labor and capital would rise even further as it would be more difficult to attract these endowments from the non-agricultural sectors.

Similarly the Armington elasticity determines the feedbacks on the international market. The elasticity determines the ability of a product to expand into other international markets or the extent to which it can be replaced by similar products of international origin which in turn determines the extent to which prices rise (fall) when the production of a sector decreases (increases). For example wheat has a high Armington elasticity, so when Dutch production falls the price stays the same as consumers can easily switch to other suppliers so producers do not get compensated by higher prices in contrast to the vegetables and fruits producers with a lower elasticity. It is difficult for the consumers of Dutch vegetables and fruits to switch to another supplier so the prices rise as a result. However when production increases the wheat farmers can significantly increase their exports while the vegetables and fruits producers can only do so marginally, therefore the price drops for the vegetables and fruits producers while it stays the same for wheat.

The methodology used in these studies has as usual some limitations. For instance, we assume the absence of transaction costs in any water exchange and furthermore, that sufficient infrastructure exists such that additional water can be abstracted at the point of use in any exchange of water abstraction permits. This assumption would overestimate the benefits of water markets. On the other hand, we assume a common shadow price for water in the benchmark equilibrium. If water abstraction is charged by volume, it is much more likely that agriculture will be charged water at a lower price than industry or public water services; if the baseline already contains this imbalance, then a water market would provide additional benefits not captured by this study. Further, in the extensions of the GTAP model used in this chapter, many of the behavioral parameters are distinguished by economic sector but not by region. This is also true for some parameters important to this chapter. Such as the elasticity of substitution between primary inputs (i.e. labor capital and land), the Armington elasticity of substitution between domestic and imported goods, and the elasticity of transformation (i.e. the mobility) of the endowments labor, capital and elements of the land and water nests. Estimating these parameters with local data might have improved the accuracy of some of the specific results in the studies considered in this chapter. The main trends and most importantly the economic mechanisms driving these trends would however remain unaltered.

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